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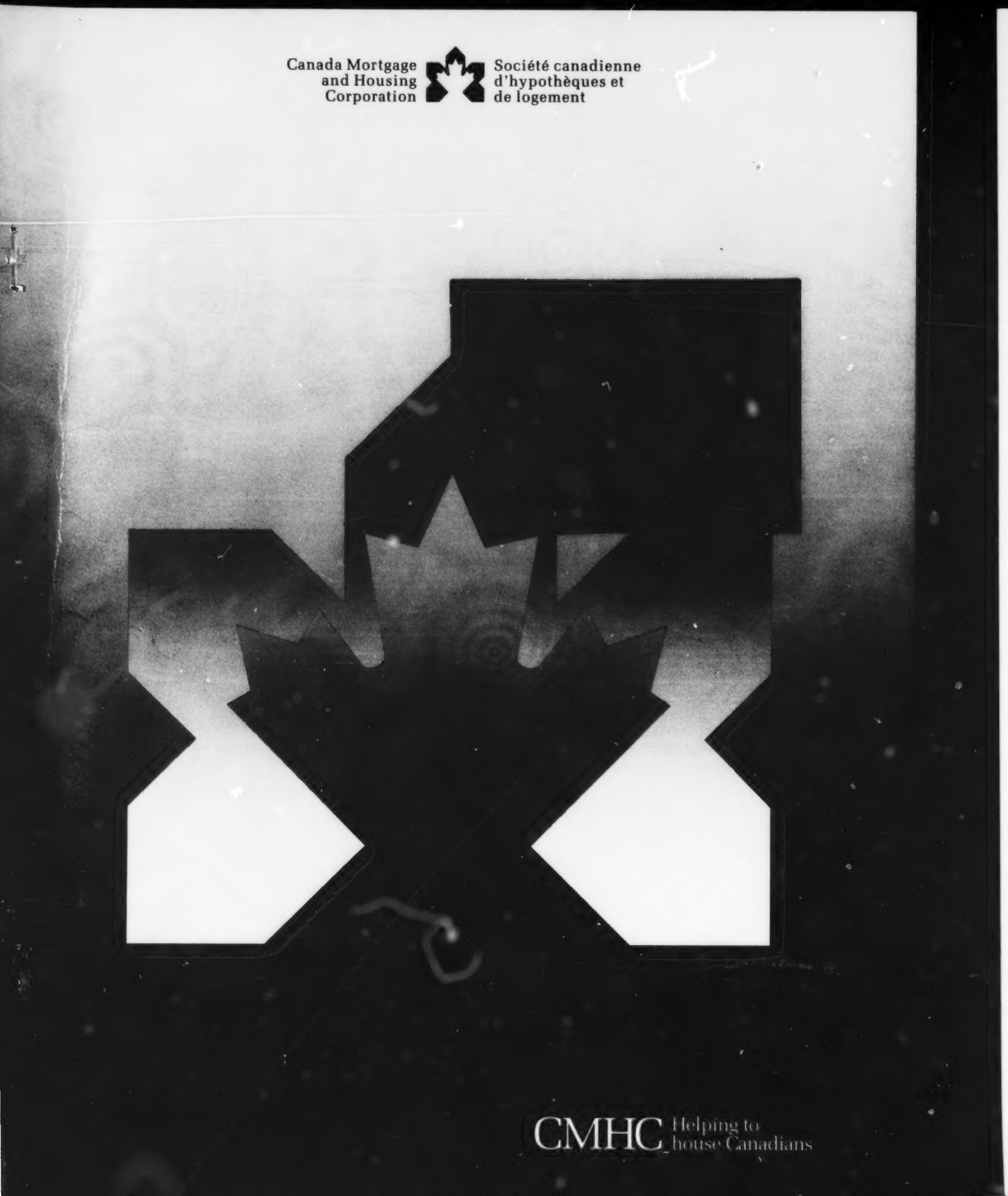

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MONITORING URBAN DEVELOPMENT IN THE CITY OF SCARBOROUGH, METROPOLITAN TORONTO

JULY, 1986 to JUNE, 1987

EMPLOYING SPOT XS EARTH SATELLITE DATA

Monitoring Urban Development in the City of Scarborough, Metropolitan Toronto July, 1986 to June, 1987 Employing SPOT XS Earth Satellite Data

by

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90-01274/

Abstract

This study examines the capabilities of SPOT XS high spatial resolution imagery as part of a larger effort to develop an accurate, cost effective method of monitoring rural-to-urban land conversion employing earth satellite imagery. First, a set of thirty photographs of satellite images prepared for the study area are displayed and described in order to provide the reader with a visual appreciation of the information source.

The study method consisted of detecting change in SPOT XS images between July, 1986 and June, 1987 for the City of Scarborough study area. Both visual change detection and computer-based change detection methods were applied to the comparison of separate images for different dates, and to the analysis of multidate, composite images. Accuracy assessments of the four change detection approaches were presented and discussed. Overall accuracies of 80% and change detection accuracies (pertaining to change classes only) of 62% were obtained from the visual comparison of two false colour composite images and from the examination of a multidate, composite image modified by supervised classification. These levels of accuracy were not appreciably different from change detection accuracies obtained from earlier studies for the same area employing Landsat MSS imagery. Recommendations were offered for improving change detection accuracies. Complementary roles for the use of satellite imagery and aerial photographs in land conversion studies were discussed in the context of size of study area.

Monitoring Urban Development in the City of Scarborough, Metropolitan Toronto, July, 1986 to June, 1987 Employing SPOT XS Earth Satellite Data

Executive Summary

This report examines the capabilities of French SPOT XS high spatial resolution satellite imagery for monitoring rural-to-urban land conversion with particular attention paid to urban land development in the northeast sector of Metropolitan Toronto. A previous report " Monitoring Urban Development in the Toronto Region Employing Landsat Earth Satellite Data " submitted to CMHC in December, 1985 served as precursor to this current research. The overall goal for both studies and subsequent research has been to develop an accurate, cost-effective method of monitoring rural-to-urban land conversion.

Three objectives have guided the research for this second report. They are:

1) to determine the improved capabilities of Landsat TM and SPOT XS imagery, in comparison with Landsat MSS, to discriminate among urban land cover types in static and dynamic settings. Particular interest is directed to the collection of visual information on the residential development process as evidenced by physical changes on land development sites.

2) to compare the strengths and weaknesses of two research methods (separate composite images comparison and multidate composite images) when treated visually, as raw images, and when treated as supervised classifications.

3) to maintain common frameworks of methodology, study area, and research questions for both the current study and the 1985 study in order to enhance comparison.

A photographic essay of raw and modified satellite images was presented to familiarize readers with the visual properties of rural-to-urban land conversion in its rural-urban fringe setting as recorded by earth satellites. Unfortunately, it was not possible to acquire suitable Landsat images, in MSS and TM modes, for the summer of 1987 due to cloud cover over the study area. Therefore, a comparison of change detection accuracies has been limited to the July, 1986 and June, 1987 SPOT XS images.

The 12,260 hectare study site is centred within the City of Scarborough, Ontario and contains examples of farmland undergoing conversion to urban land uses as well as a diversity of residential, commercial and industrial uses.

The study methodology consisted of two phases and involved four, separate treatments. In the first phase separate, composite images of the study area for the two dates were compared and analyzed and for land cover change. One comparison was based on separate, false colour composite images. The other comparison utilized separate composite images, modified by supervised classification. In the second phase a simple multidate composite image and a multidate composite image, modified by supervised classification, were analyzed for evidence of land cover change.

Accuracy assessment was determined by systematically sampling the land cover change status of 930 pixels for each of the four change detection approaches and comparing this change status with photomaps of the study area for April, 1986 and April, 1987. Additional land cover information was obtained from topographic maps, land use reports prepared by the Scarborough Planning Department, field reconnaissance and oblique aerial photographs.

Best overall accuracies of approximately 80% and change detection accuracies of approximately 62% were obtained from two of the four change detection approaches; namely, 1) the visual comparison of two false colour composite images and 2) examination of a multidate, composite image modified by supervised classification. These levels of accuracy are not appreciably different from change detection accuracies obtained from the author's earlier studies of the same subject area employing Landsat MSS images (Martin 1985, 1989). The reason for this lack of improved change detection capability, despite the improved spatial resolution of SPOT imagery, is related to the limitations of existing land cover classification systems and multispectral classification algorithms.

In the concluding section several improvements are suggested. Use of hard copy image transparencies projected by optical transfer devices onto work surfaces may be preferable to the use of expensive image processing computers. Contextual information contained in satellite images and collateral information derived from other sources can improve change detection accuracies obtained from computer image processing. Various change detection methods may

need to be applied to a study area in a spatially selective manner. Improved classification systems and classification algorithms better suited to the spectral and spatial characteristics of SPOT XS and future higher resolution satellite imagery should be devised and tested. Until these improvements are realized it will be best if use of current satellite imagery for change detection is limited to region-wide synoptic monitoring of change and more spatially detailed change detection is left to conventional aerial photographic and field survey methods.

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Acknowledgements

The author would like to acknowledge the very helpful collaboration of colleague, Dr. P.J. Howarth, in recent SPOT satellite research. Evidence of this fruitful association is duly reflected in the References. Finally, special thanks are offered to Peter Spurr, Project Officer for this contract. His encouragement and constructive comments, beginning in 1984, have helped shape and direct this research.

Introduction

The overall goal of this research is to develop an accurate, cost-effective method of monitoring rural-to-urban land conversion employing earth satellite data. Successful monitoring of the residential development process by remotely observing the physical manifestations of land development (site clearing, house construction, installation of hard services and landscaping) is the longer term focus of this research. This report presents the findings of the principal investigator's second research project funded by CMHC and dealing with the monitoring of urban development.

The first report, "Monitoring Urban Development in the Toronto Region Employing Landsat Earth Satellite Data" was submitted to CMHC in December 1985. In this report the principal investigator introduced remote sensing and computer-based image processing concepts and then employed them in the analysis of land cover change in the Scarborough study area between 1974 and 1981. Satellite information was obtained from Landsat MSS imagery, with pixel spatial resolution of approximately 80 m x 80 m for the years 1974, 1978 and 1981. This report also explored the potential advantages of employing improved satellite imagery for monitoring urban development by examining simulated Landsat Thematic Mapper (TM) imagery, with pixel spatial resolution of 30 m x 30 m, and simulated SPOT multispectral (XS) imagery, with pixel spatial resolution of 20 m x 20 m.

This second report builds upon knowledge gained from the earlier research by examining rural-to-urban land conversion employing actual SPOT XS imagery with spatial resolution of 20 m x 20 m. Three objectives were identified in the research proposal:

1) The improved capabilities of Landsat TM and SPOT XS imagery (in comparison with Landsat MSS imagery) to discriminate among urban land cover types in static and dynamic settings will be evaluated. Particular interest will be directed to the collection of visual information on the residential development process as evidenced by physical change on development sites.

2) A comparison will be made of the strengths and weaknesses of separate composite images comparison and multidate composite images when examined visually, as raw images, and when modified by

supervised classification.

3) Because this research is treated as an extension of the applicant's previous CMHC research, there will be an attempt to maintain a comparable framework of methodology and study area and to deal with research questions raised in the 1985 report.

Following this Introduction the report is organized into six sections. Section 2 provides a visual introduction to the SPOT XS imagery for the study area and compares its visual and spectral characteristics with Landsat MSS imagery, employed in the earlier study and SPOT Panchromatic imagery. Section 3 presents the research methodology. In section 4 the approach to accuracy assessment of change detection is described. The results of analysis are presented in section 5. Discussion of the research findings is presented in section 6. Conclusions follow in section 7.

Visual Characteristics of SPOT XS

In this section we will examine and discuss the visual properties of satellite imagery employed in the study. Thirty photographs are arranged in a sequence that links this current study with the 1985 study and potential future investigations. Figures 1 and 2 present Landsat MSS images of the study area and enable us to note the contrasting, improved visual quality of the SPOT XS imagery that forms the mainstay of this current study. The next 22 figures provide specific, visual information from the SPOT XS imagery. The remaining 6 figures reveal the improved visual characteristics of high spatial resolution SPOT Panchromatic imagery.

Figure 1 presents a 1982 Landsat MSS (80 m x 80 m pixel spatial resolution) three band, false colour composite image of the central portion of the study area. In Figure 2 a smaller portion of this image is placed side-by-side with a SPOT XS (20 m x 20 m spatial resolution) three-band false colour image for purpose of comparison. The improved visual character of SPOT XS imagery as a result of higher spatial resolution pixels is evident.

A 22 July, 1986 three band false colour composite image of the entire study area is presented in Figure 3. In the Figure one can observe the general progression of urban land cover in the lower half of the Figure to rural-urban fringe land cover at the top of the Figure. Specific features of note include Highway 401, the CPR

switching yard, two golf courses, wooded ravines, large tracts of residential and industrial/commercial land and a zone of active land development between urban and rural zones. A few, small clumps of cloud can be observed at the top left of the Figure. Position of cloud shadow on the ground relative to actual cloud indicates that the summer sun is low and in the southeast as appropriate of a morning overflight by the satellite. Figure 4 presents a 4 June, 1987 three-band false colour composite image of the same study area. Changes in land cover between these two images is the principal concern of this study.

All SPOT XS false colour composite images in this study are composed of three bands representing discrete segments along the visible portion of the electro-magnetic spectrum. Figures 5, 6, and 7 depict band 3 (0.79 - 0.89 um), band 2 (0.61 - 0.68 um) and band 1 (0.50 - 0.59 um) for the central portion of the study area on 4 June, 1987.

When loaded through the red, green and blue colour guns of the video monitor in the conventional sequence above we obtain the false colour images recorded in the previous figures. A segment of the study area experiencing considerable land development is depicted at a larger scale by enlarging the picture elements or pixels for bands 3, 2 and 1 of the 22 July, 1986 image.

Three-band false colour images of the large development sites in the 22 July, 1986 image and noted in the preceding three Figures are displayed in Figures 11 and 12. Attention is directed to the colour hue variations within the development sites. These variations in colour hue reveal different stages of construction. Very pale blue depicts land cleared of topsoil while pale blue indicates roads and housing construction, installation of sewerage and water pipes and mounds of stockpiled topsoil. These same development sites are displayed in false colour for 4 June, 1987 in Figures 13 and 14. The progression of on-site construction over the 11 month period can be observed by comparing Figures 11 and 12 with Figures 13 and 14.

Figures 15 and 16 present computer-generated supervised classifications of the land cover in the study area for 22 July, 1986 and 4 June, 1987. Five classes of land cover are depicted; residential (red), industrial/commercial (yellow), land development (blue), open space (olive), and woods (green). The original classification contained 10 classes including 2 residential classes, 2 development classes, 3 open space classes and 2 woods classes. These have been reduced to 5 classes in order to concentrate on the main stages of land

conversion and to simplify and improve the visual product of classification. It is possible to obtain a visual appreciation of rural-to-urban land conversion within the study area by denoting the progression of land development between the two dates.

The supervised classifications of the large development sites is shown at a larger scale for the 22 July, 1986 and 4 June, 1987 images. Two classes of land development are depicted with cleared land in light blue and land undergoing construction in dark blue. Because the cleared land class may appear at two phases of the development process - when topsoil is removed and after road beds and sewerage and water pipes are installed but before house construction begins - a seemingly illogical sequence may be observed in which cleared land (light blue) may follow land on which construction is under way (dark blue).

Figure 19 displays a supervised classification of the central portion of the study area for 4 June, 1977. In addition to the 2 classes of land development discussed above are 2 classes of residential land cover; low density residential (pink) and medium and high density residential (red).

A multidate, composite image of the study area is displayed in Figure 20. Band 2 of the 22 July, 1986 SPOT XS image was loaded through the red colour gun of the video monitor and band 2 of the 4 June, 1987 image is loaded through the green colour gun of the video monitor. Land parcels undergoing development at the first date, but completed before the second date, are displayed in red. Land parcels undergoing development at the second date, but not at the first date, are displayed in green. Land parcels undergoing development at both dates are displayed in yellow. Areas not undergoing change between the two dates are displayed in hues of olive and grey. Land development is concentrated in the upper half of the study area but many, small, infill development parcels are noted elsewhere. A segment of Highway 401 appears to be undergoing reconstruction during the study period.

More detailed information regarding land development on large development sites and on small, scattered, infill development sites is presented in Figure 21 and Figure 22.

A supervised classification of the multidate, composite image of the study area is displayed in Figure 23. Four no-change land cover classes and three change land cover classes are presented. The no-change classes include residential (red), industrial/commercial

(yellow), open space (olive) and woods (green). Change classes include development in July, 1986 (dark blue), development in June, 1987 (mauve), and development at both dates (light blue). A larger scale image of supervised classification at the large development sites is shown in Figure 24.

Six SPOT Panchromatic images of locations in and near the study area for 1987 are presented in Figures 25 through 30. Because a 1986 Panchromatic image of the study area was not available this higher spatial resolution imagery was not employed for change detection in this study. Nevertheless, the potential contribution of this SPOT imagery to change detection studies on the rural-urban fringe can be appreciated as a result of the additional, visual information provided by images composed of 10 m x 10 m pixels. Panchromatic images are captured only for one band (0.51 -0.73 um) thus they can be displayed only in grey tones on a video monitor.

Figures 25 and 26 present the large development site at two scales. Comparison of Figures 25 and 26, in the single band panchromatic mode, and Figures 13 and 14, in the three-band multispectral mode, indicates the additional information available from the former mode. Even though some sharpness of detail present on the video monitor is lost in the photographic prints it is still possible to count houses under construction on the development site. Houses can be discerned also on certain residential streets.

Figures 27 and 28 provide additional information for other locations within the study area. Vehicles can be observed on Highway 401. Figure 29 provides more detail of a golf course within the study area. At the top of the Figure individual houses on estate lots can be identified. Beyond the study area Figure 30 provides a view of Toronto harbour, the Island Airport, the railway lands and highrise office buildings in the CBD. At the centre of the image the presence of the CN Tower is revealed by its shadow. Boats and their v-shaped wakes can be counted in the harbour. Boat slips at Ontario Place Marina and at yacht clubs on the Toronto islands are visible.

When SPOT imagery is available in both XS and Panchromatic modes for the same location, for reasonable close dates, it is possible to combine this imagery to take advantage of the improved spatial resolution of the Panchromatic mode and the multi-band spectral characteristics of the XS mode. We will refer to this again in the concluding section of the report.

Having provided an overview of the visual characteristics of the SPOT XS imagery employed in this study and having compared it, briefly, to Landsat MSS and SPOT Panchromatic imagery, in order to provide the reader with an appreciation of its potential benefits and limitations, we now review the study methodology in the following section.

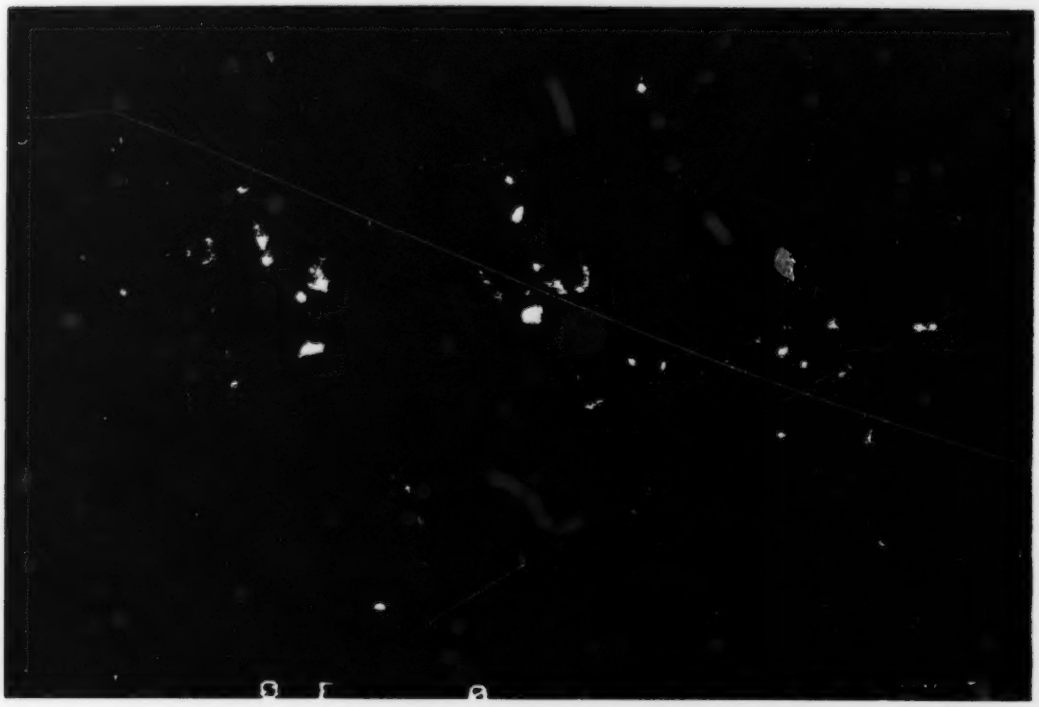

Figure 1: Landsat MSS three-band, composite, false colour, July, 1982 image of a portion of the Scarborough study area.

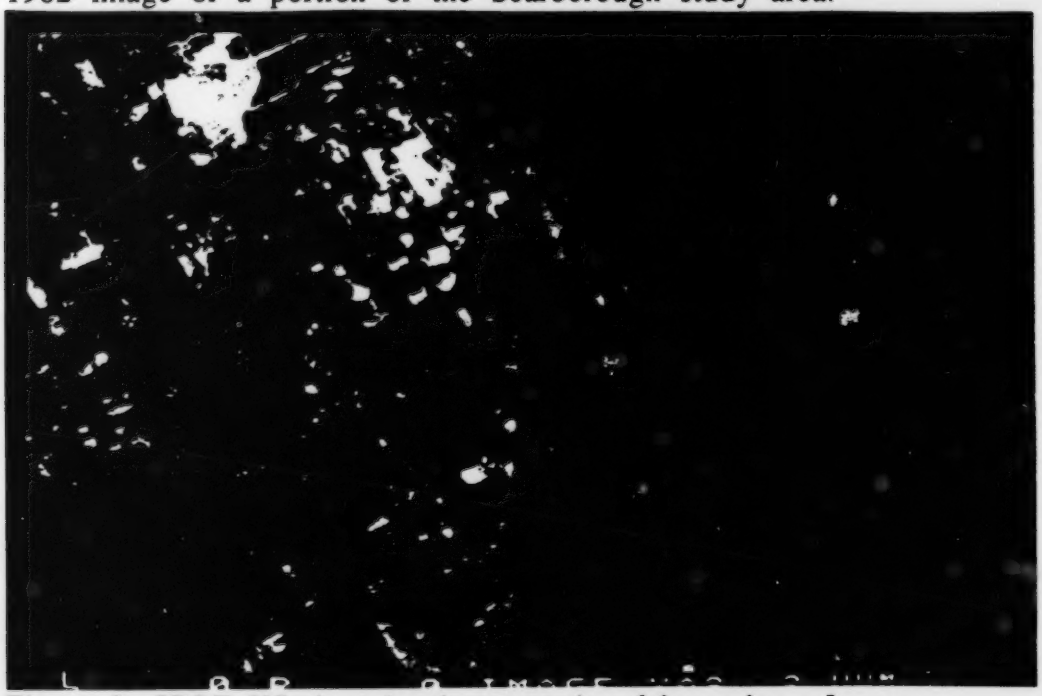

Figure 2: SPOT XS three-band, composite, false colour, June, 1987 image (left) and Landsat MSS three-band, composite, false colour, July, 1982 image (right) of the central portion of the Scarborough study area.

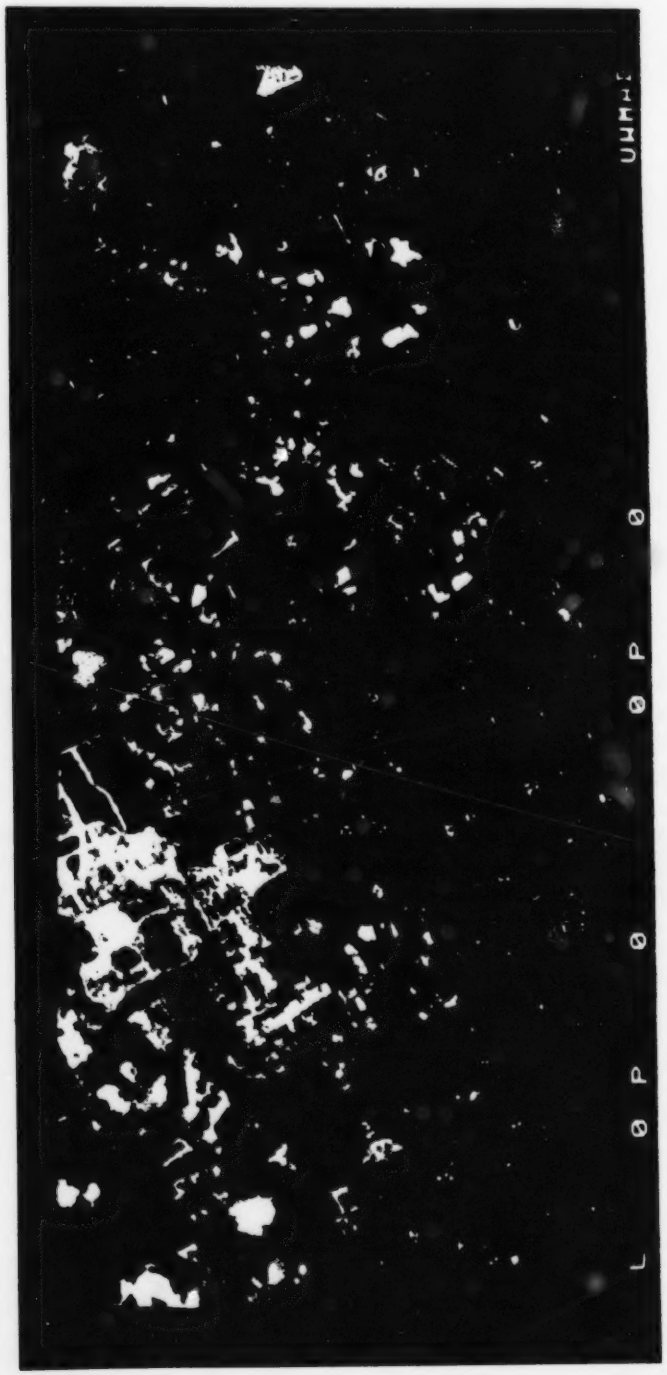

Figure 3: SPOT XS three-band, composite, false colour, July, 1986 image of the Scarborough study area.

Figure 4: SPOT XS three-band, composite, false-colour, June, 1987 image of the Scarborough study area.

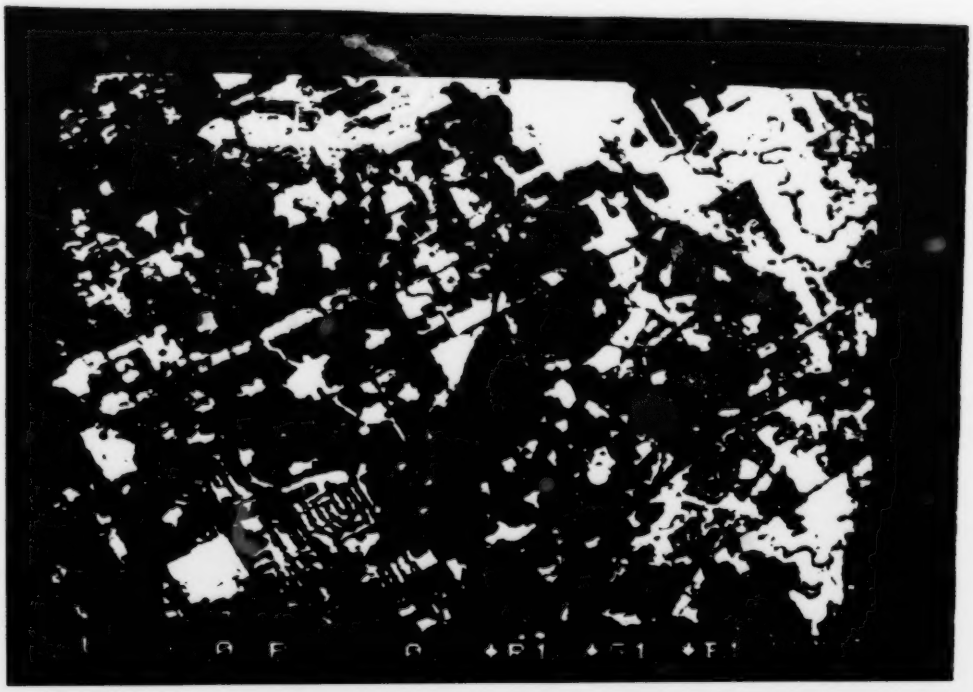

Figure 5: SPOT XS band 3, June, 1987 image of a central portion of the Scarborough study area.

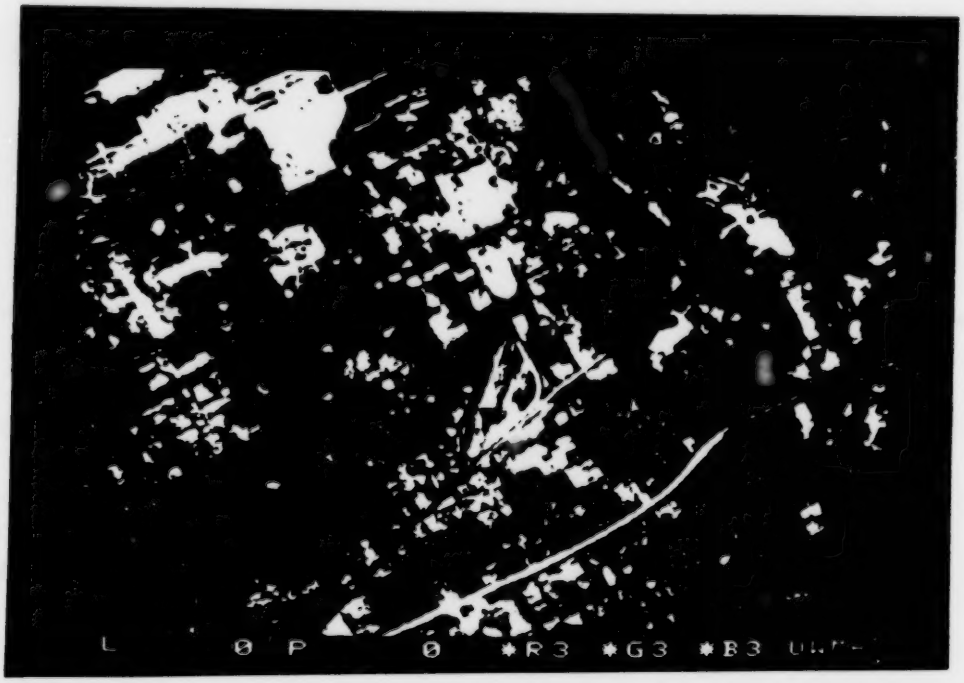

Figure 6: SPOT XS band 2, June, 1987 image of a central portion of the Scarborough study area.

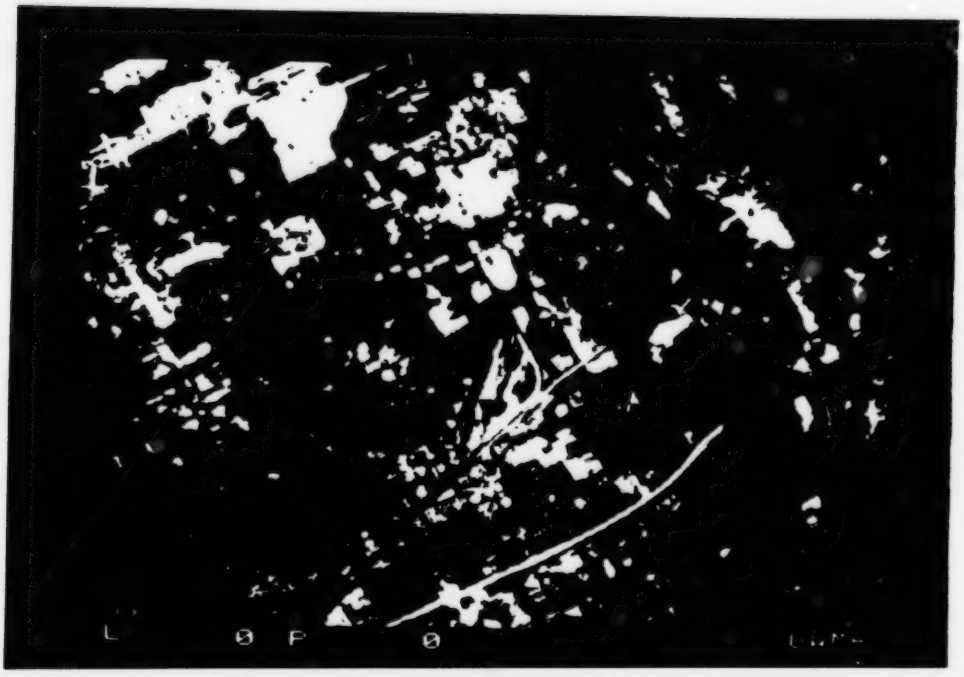

Figure 7: SPOT XS band 1, June, 1987 image of a central portion of the Scarborough study area.

Figure 8: SPOT XS band 3, enlarged July, 1986 image of large development sites in Scarborough study area.

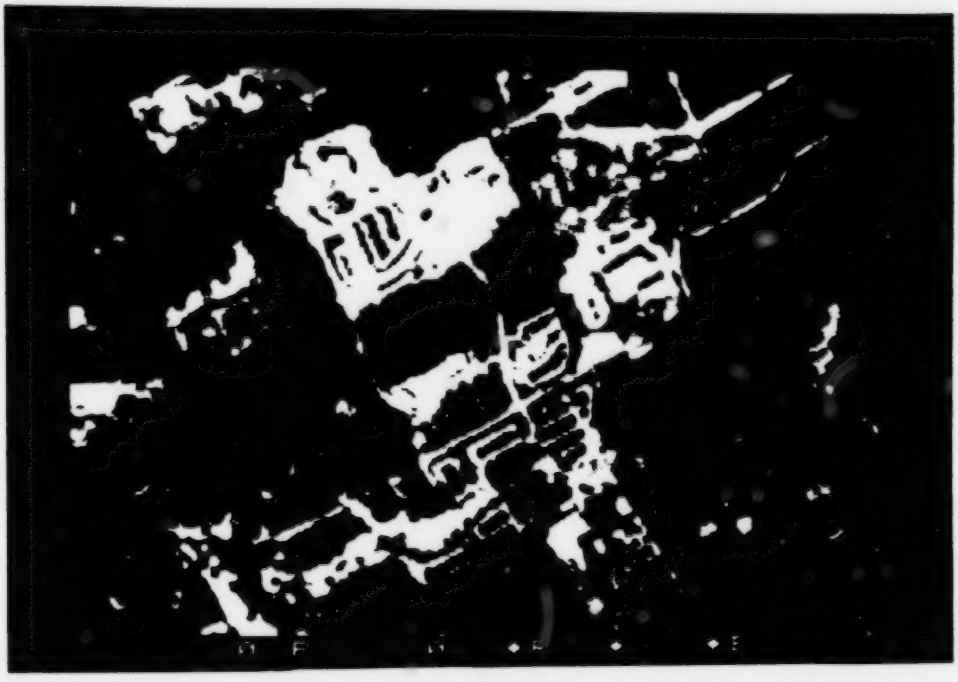

Figure 9: SPOT XS band 2, enlarged July, 1986 image of large development sites in Scarborough study area.

Figure 10: SPOT XS band 1, enlarged July, 1986 image of large development sites in Scarborough study area.

Figure 11: SPOT XS three-band, enlarged, composite, false colour, July, 1986 image of large development sites in Scarborough study area.

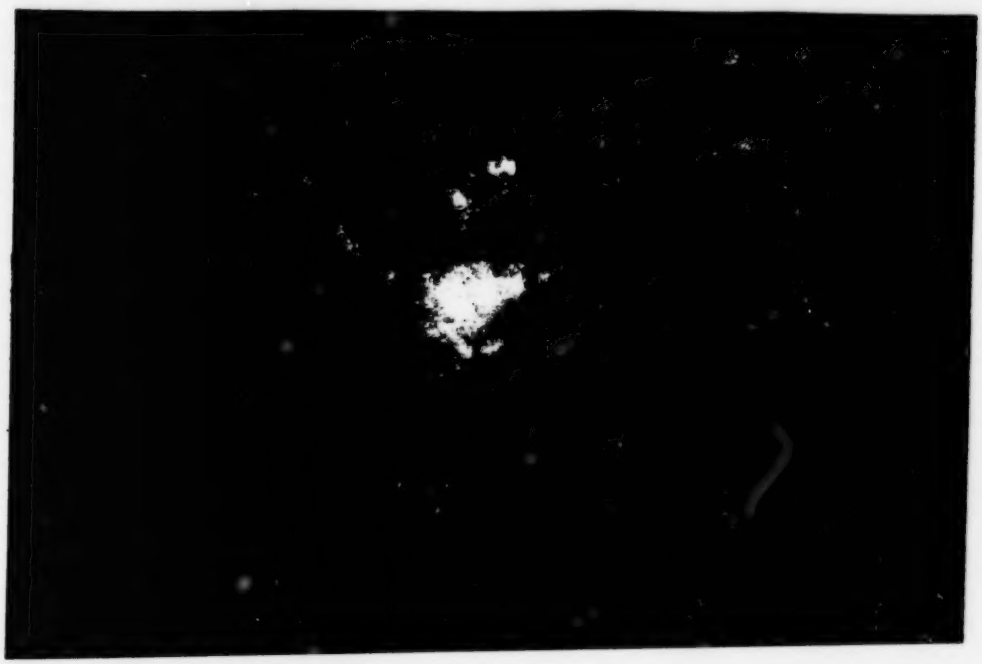

Figure 12: SPOT XS three-band, greatly enlarged, composite, false colour, July, 1986 image of large development sites in Scarborough study area.

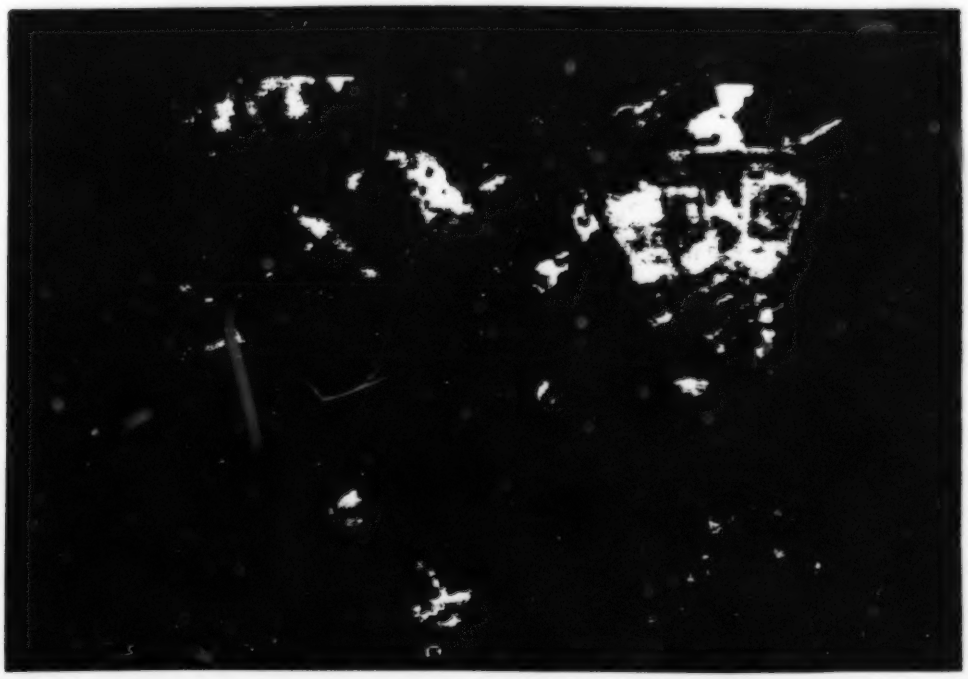

Figure 13: SPOT XS three-band, enlarged, composite, false colour, June, 1987 image of large development sites in Scarborough study area.

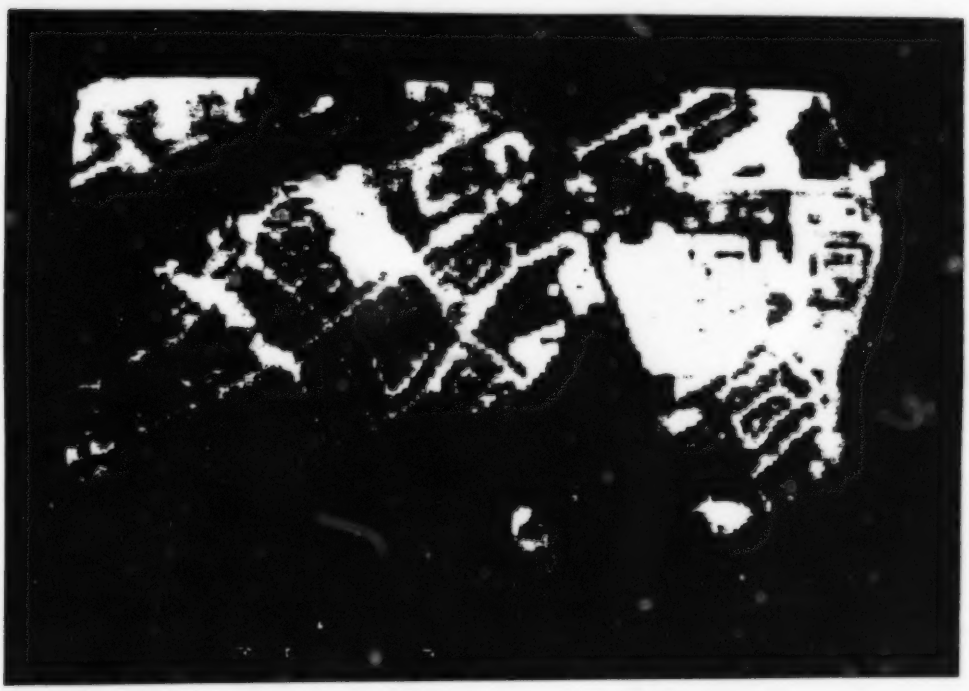

Figure 14: SPOT XS three-band, greatly enlarged, composite, false colour, June, 1987 image of large development sites in Scarborough study area.

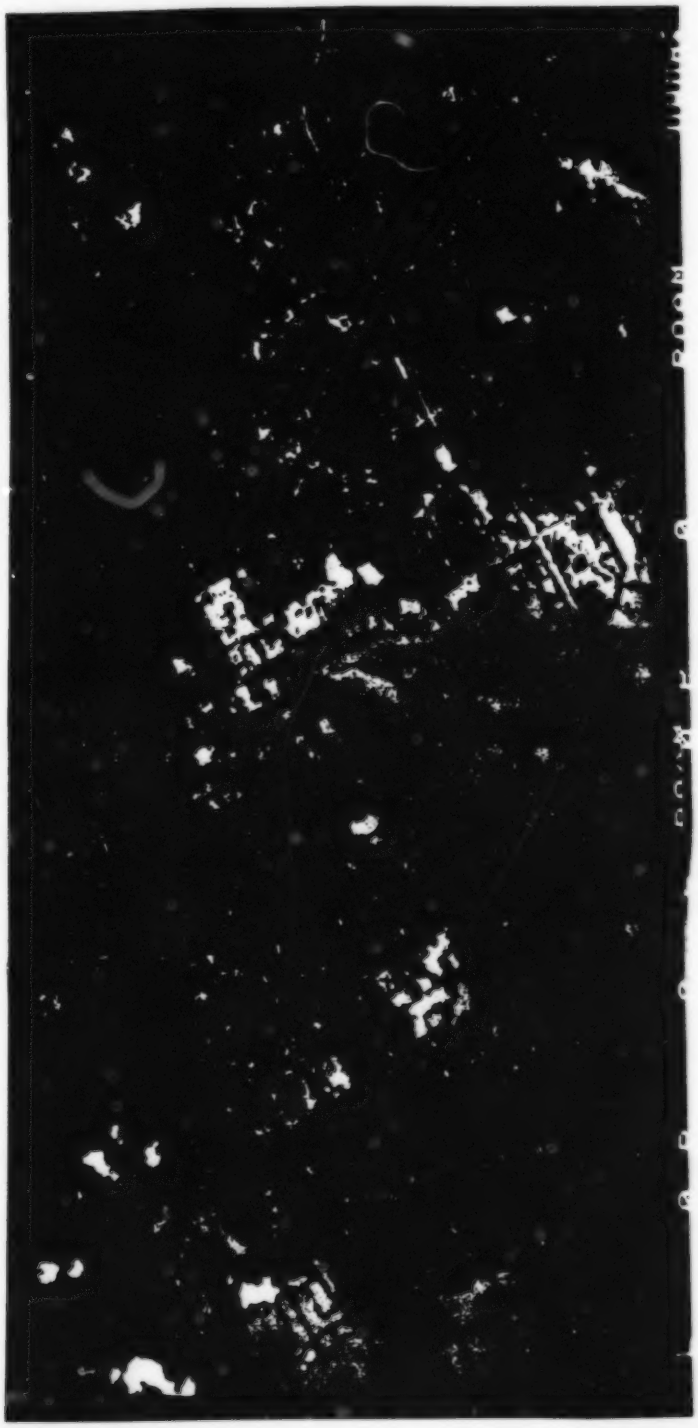

Figure 15: SPOT XS supervised classification of the July, 1986 composite image of the Scarborough study area; residential (red), industrial/commercial (yellow), land development (blue), open space (olive), and woods (green).

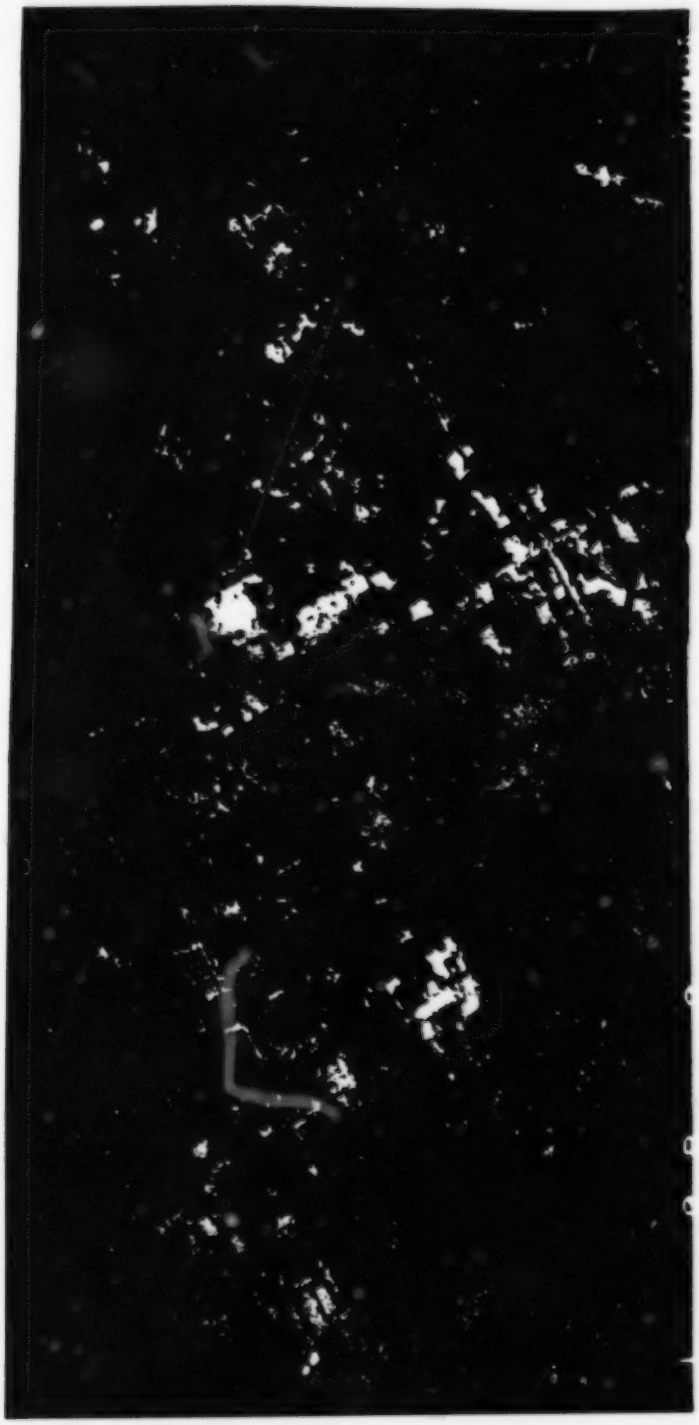

Figure 16: SPOT XS supervised classification of the June, 1987 composite image of the Scarborough study area; residential (red), industrial/commercial (yellow), land development (blue), open space (olive), and woods (green).

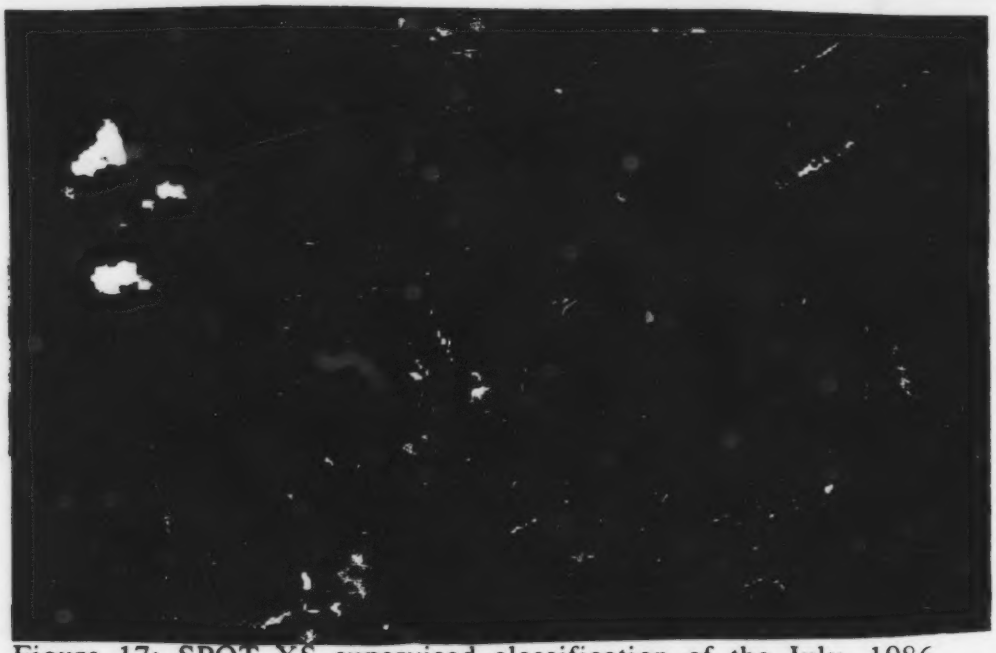

Figure 17: SPOT XS supervised classification of the July, 1986 composite image, enlarged for large development sites in the Scarborough study area. Two classes of land development are depicted; cleared land (light blue), and land undergoing construction (dark blue). Other land cover classes described in Photo 16 caption.

Figure 18: SPOT XS supervised classification of the June, 1987 composite image, enlarged for large development sites in the Scarborough study area. Two classes of land development are depicted; cleared land (light blue), and land undergoing construction (dark blue). Other land cover classes described in Photo 16 caption.

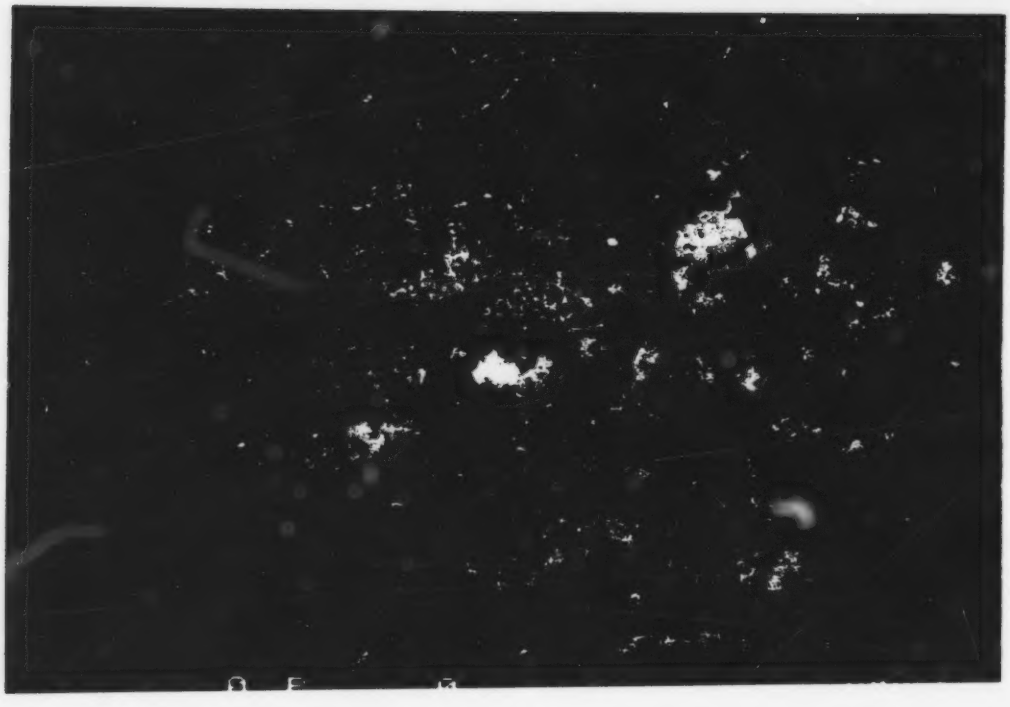

Figure 19: SPOT XS supervised classification of the June, 1987 composite image of the central portion of the Scarborough study area; low density residential (pink), medium and high density residential (red), industrial/commercial (yellow), cleared land (light blue), land undergoing construction (dark blue), open space (olive), and woods (green).

Figure 20: SPOT XS multidate, composite image of the Scarborough study area consisting of band 2, July, 1986 and band 2, June, 1987; change under way in July, 1986 (red), change under way in June, 1987 (green), change under way at both dates (yellow), and no-change (grey tones).

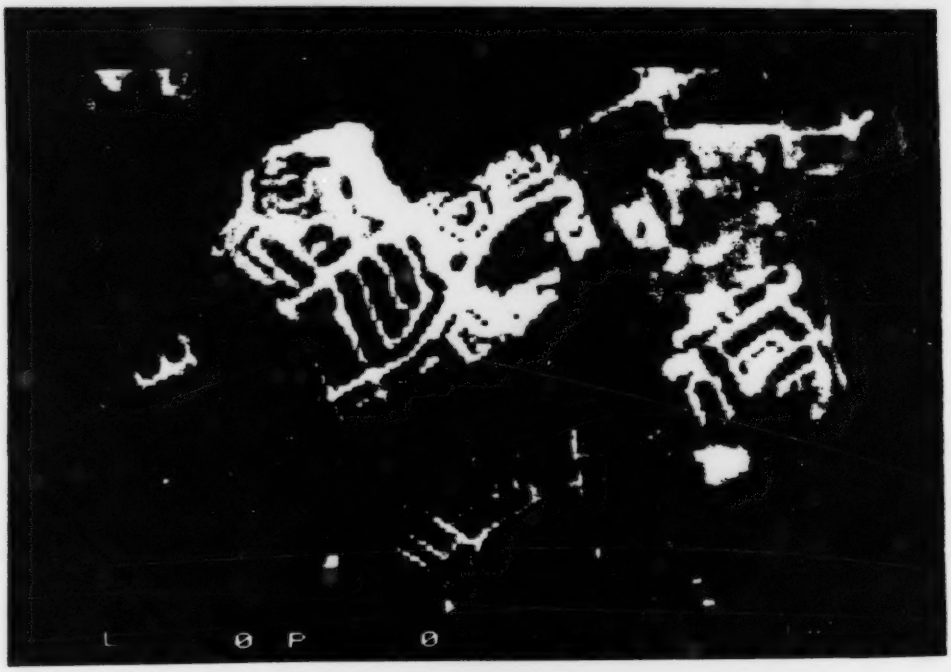

Figure 21: SPOT XS multidate, composite image of large development sites in the Scarborough study area for the July, 1986 to June, 1987 period.

Figure 22: SPOT XS multidate, composite image of small, scattered infill development sites in the Scarborough study area for the July, 1986 to June, 1987 period.

Figure 23: SPOT XS supervised classification of the multidate, composite image consisting of band 2, July, 1986 and band 2, June, 1987, Scarborough study area; no change classes include - residential (red), industrial/commercial (yellow), open space (olive), and woods (green); change classes include - development in July, 1986 (dark blue), development in June, 1987 (mauve), and development at both dates (light blue).

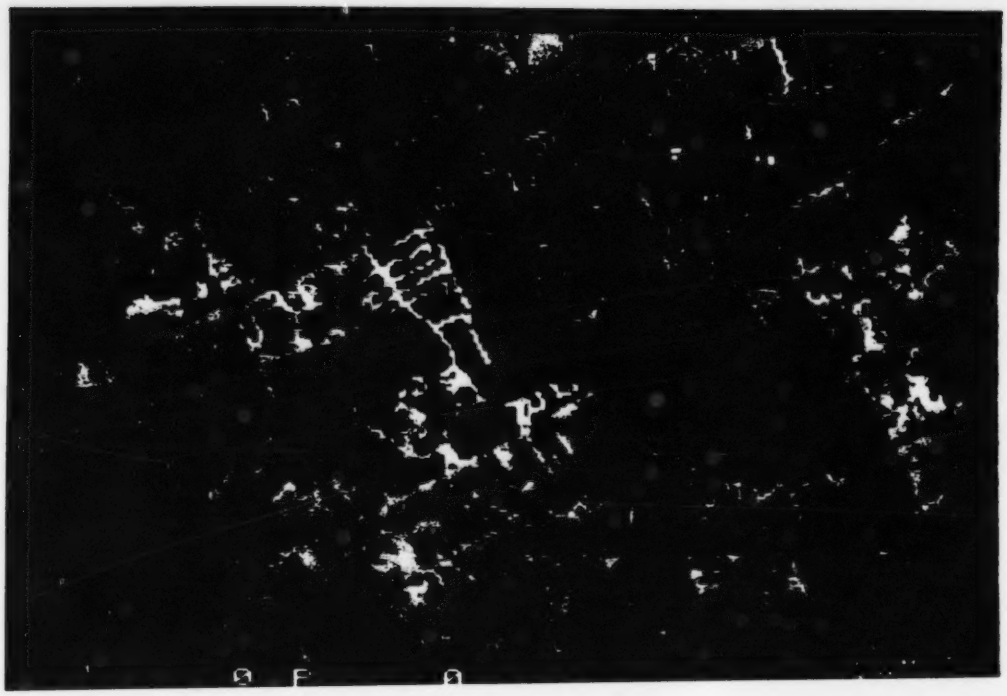

Figure 24: SPOT XS supervised classification of the enlarged multidate composite image for July, 1986 and June, 1987 Scarborough study area, with large development sites. No change and change classes are described in the Photo 23 caption.

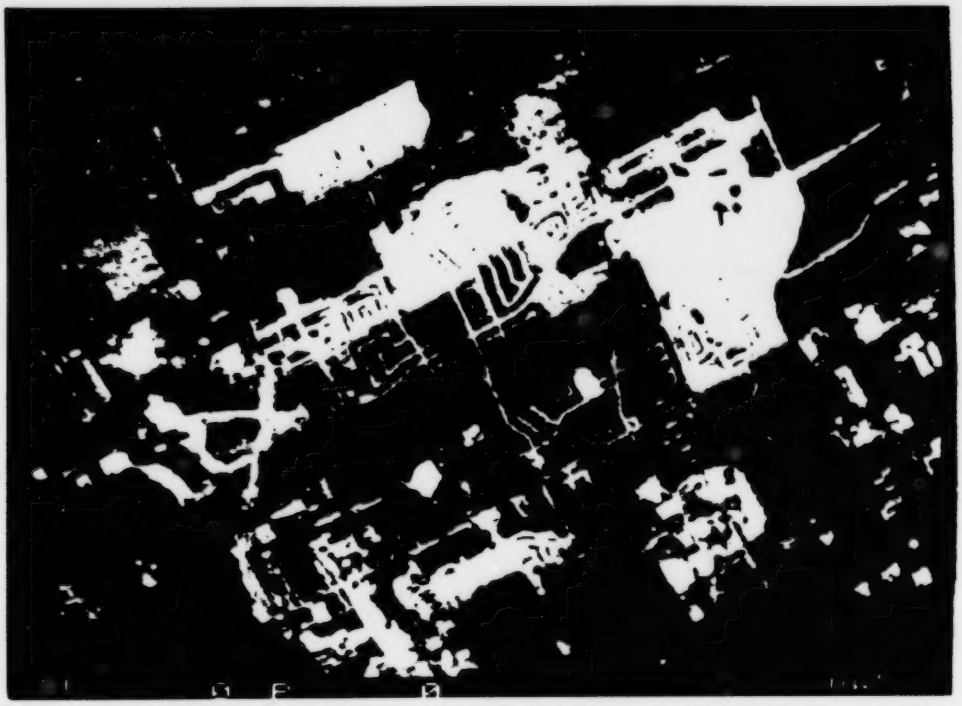

Figure 25: SPOT Panchromatic, enlarged, June, 1987 image of large development sites in the Scarborough study area.

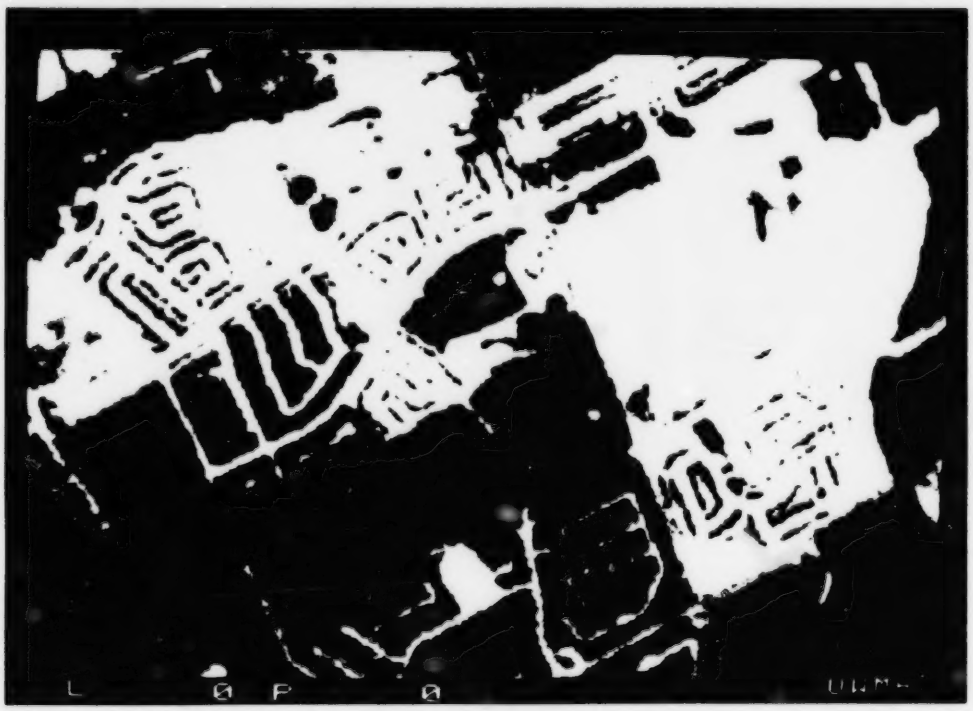

Figure 26: SPOT Panchromatic, greatly enlarged, June, 1987 image of large development sites in the Scarborough study area.

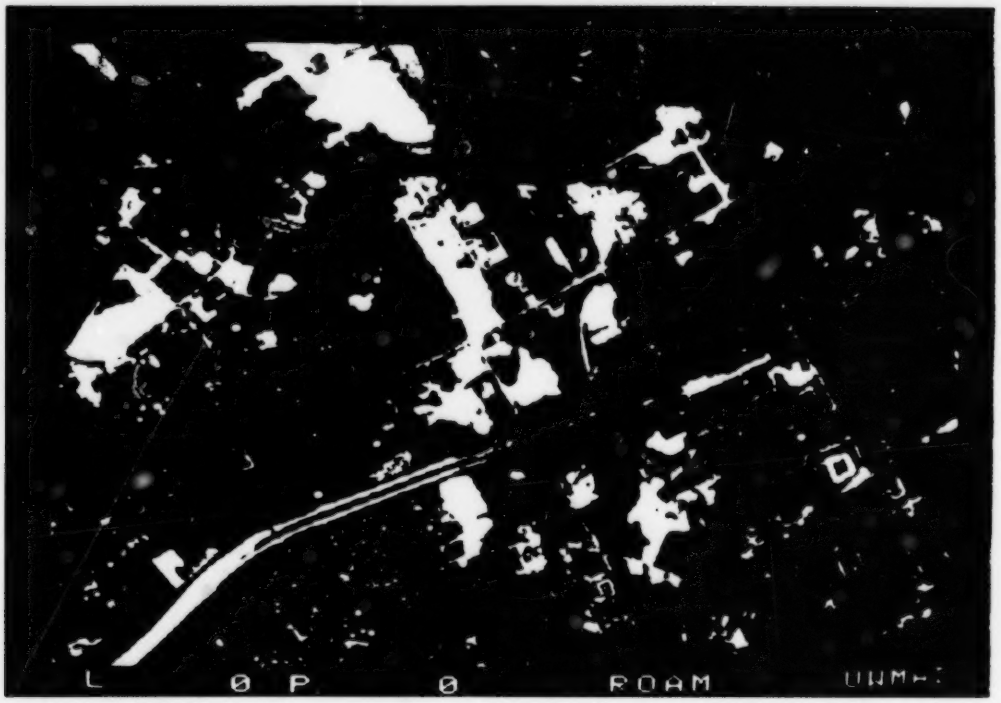

Figure 27: SPOT Panchromatic, June, 1987 image of small, scattered infill development sites in the Scarborough study area.

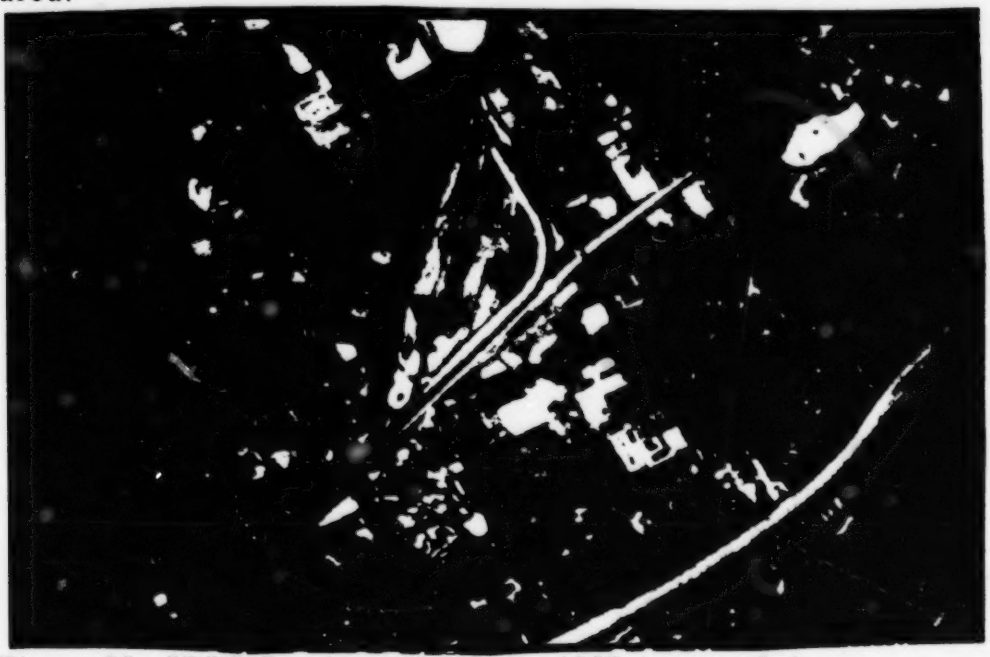

Figure 28: SPOT Panchromatic, June, 1987 image of the Canadian Pacific Railway switching yard in the Scarborough study area.

Figure 29: SPOT Panchromatic, June, 1987 image of exurban land cover in the Scarborough study area.

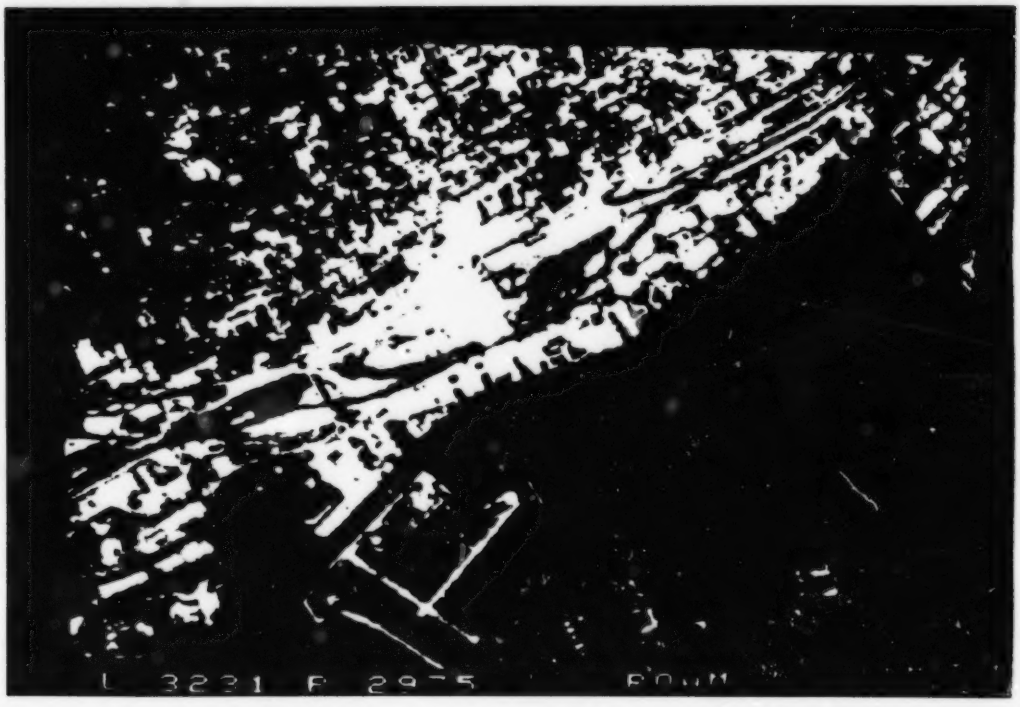

Figure 30: SPOT Panchromatic, June, 1987 image of Toronto harbour southwest of the Scarborough study area.

Methodology

As stated in the original study proposal it was the researcher's intention to assess the relative capabilities of three types of satellite imagery -Landsat MSS and TM and SPOT XS - to detect accurately rural-to-urban land conversion between summer, 1986 and summer, 1987. These three types of imagery represent a progression of improved spatial resolution. Past experience with deficiencies in detecting urban development employing Landsat images strengthened our expectations that SPOT XS imagery would prove to be superior to all Landsat products. Suitable SPOT XS images were acquired for 22 July, 1986 and 4 June, 1987. Unfortunately it has not been possible to acquire suitable Landsat images, either in the MSS or TM modes, for the summer of 1987 due to the presence of cloud cover over the study area during satellite overflights. For this reason it has been impossible to compare change detection accuracies among the satellite image types. Instead, this study focuses on a comparison of change detection accuracies between two change detection methods, employing two separate treatments for the 1986 and 1987 SPOT XS images.

The area selected for study is centred within the City of Scarborough, Ontario. The 12,260 hectare site includes a wide range of land use types found within a rapidly growing metropolis. The southern two thirds of the study area underwent urban development after World War II and contains a diversity of residential and commercial uses. In the northern third of the study area, farmland, undergoing conversion to urban uses, is widespread. Large tracts of warehousing and manufacturing are present, particularly adjacent to Highway 401 traversing the study area east-to-west and Highway 404 extending northward from Highway 401. Several large surface area features in the study area are prominent from the air. These include the triangular shaped CPR switching yard, the former Bear Road land fill site now being converted to a recreation site, the Metropolitan Toronto Zoo and a series of linear, northwest to southeast wooded ravines that lend a sharp vegetative contrast to the man-made inorganic road and roof top surfaces associated with urban development.

The study methodology consisted of two phases and involved four separate treatments. (See Figure 31) In the first phase separate, composite images of the study area for two dates were compared and

analyzed for land cover change. One comparison was based on separate, false colour composite images. The other comparison utilized separate composite images, modified by supervised classification.

In the second phase a simple multidate composite image and a multidate composite image, modified by supervised classification, were analyzed for evidence of land cover change.

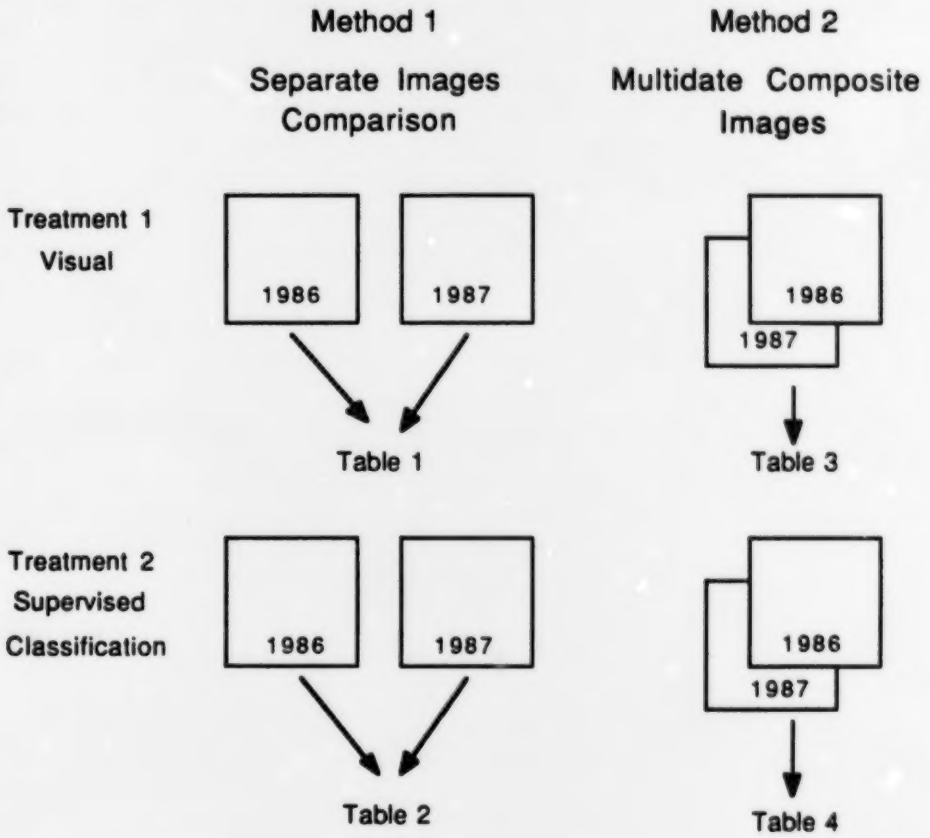

Figure 31: Schema of Study Methodology

Separate Images Comparison Method

In the separate images comparison phase (henceforth termed "separate images method") , 18 land cover and land use change categories among 3 major groups (no conversion, rural-to-urban conversion and other conversion) were selected for identification. Five classes of static land cover were the primary building blocks of

information obtained from the two images and from which the 13 dynamic categories could be derived by comparing these images. These five classes of static land cover also represented all land not converted to other cover types during the one year period. Eight dynamic classes of land cover make up the more common rural-to-urban land conversion groups and 5 dynamic classes of land cover form the much less common urban-to-development, urban-to-rural and specific urban-to-urban and rural-to-rural changes specified here as the "other conversion group".

The residential land cover class includes all types of residences from low density single family dwellings on lots exceeding 400 square metres (one pixel) to high density multiple family dwellings located within a 400 square metre tract.

Spatially-extensive land covers such as industrial parks and shopping plazas with their low rise structures and large, vehicular parking areas are principal members of the industrial/commercial land cover class. Also included in this class are manufacturing, warehousing and retail land covers having elongated linear form and adjacent to transport and utility corridors. The two land cover classes are grouped together because of their spectral and locational similarity.

The open space class contains cultivated farmland and parkland components. New crops, characterized by the dominance of bare soil, and mature crops, where bare soil is present to a very limited degree, comprise the cultivated farmland component while low, clipped, herbaceous cover, present in outdoor recreational spaces, utility corridors, pastures and highway margins and rough pasture-like terrain containing scattered woody plants, comprise the parkland component.

Deciduous and coniferous trees, standing in close proximity, such that the understory is obscured, constitute the woods class.

Land conversion classes represent land use and land cover dynamics. Rural-to-urban land conversion takes place as land shifts from land use and land cover classes in the vegetation group(open space and woods), passes through the land development class and joins the urban group (residential and industrial/commercial). "Other conversion" includes the less common land use and cover changes within groups (eg. woods to open space) and urban-to-development, urban-to-rural and development-to-rural land conversion categories.

The process of rural-to-urban land conversion on a particular site may unfold quickly in a period of several months or slowly over several years. The development land cover class records and spatially delimits the physical conversion of land from non-urban to urban cover. As a transitional cover type, land development may or may not be present in satellite imagery depending on the date of overflight. Two components of development may be identified on SPOT imagery; cleared land and construction under way. Denuded of vegetation and top-soil, cleared land exhibits relatively uniform, high reflectance. Sites with construction underway display more varied high reflectance associated with building foundations and superstructures, construction materials, roads and utilities undergoing installation and earth debris on paved roads and fields.

In the first of the separate images treatments, three-band false colour images, one for each date, were displayed on a split screen video monitor of a Dipix Aries III image analysis system. (See Figures 3 and 4.) Bands 3, 2 and 1 were loaded through the red, green and blue colour guns respectively. Sample pixels in these paired images were examined to determine land cover class and identify land cover changes. (See "Accuracy Assessment" section for further discussion.)

In the second of the separate images treatments the false colour images for the two dates were separated into discrete land cover classes using the supervised classification method and employing the Dipix image analysis system. Supervised classification began with the selection of training areas for ten static land cover classes. Spectral signatures were generated from the training area data and were employed in a maximum likelihood classifier to place all pixels in 1 of 10 land use/cover categories which were subsequently merged to provide the 5 static categories of land cover described previously. The two classified images were displayed on the split screen for accuracy assessment. (See Figures 15 and 16.)

Multidate Composite Image Analysis

In the second phase of the methodology two treatments were carried out. A simple multidate composite image and a multidate composite image, modified by supervised classification, were analyzed. The multidate composite image (henceforth termed "multidate method"), used in both analyses, was formed by loading a corrected band 2 image for both dates through the red and green colour guns of the CRT monitor, in effect, overlaying them to produce a new colour-composite image in which change can be inferred from

variations in grey tone or colour hue. (See Figure 20.) Band 2 of SPOT XS was selected because it provided the best visual discrimination of rural-to-urban land conversion among land cover groups in the study area.

From an initial, visual comparison of this multidate image with aerial photographs and ancillary land cover information it was determined that the red hue represented the spectral response of the SPOT XS to land undergoing urban development on July 22, 1986 but completed before June 4, 1987 and that the light green hue represented the spectral response of the SPOT XS to land undergoing urban development on June 4, 1987 but not at the time of the first image capture. A pale, yellow hue represented the spectral response of the SPOT XS to land in the development phase of conversion at both dates. Areas deemed to be in residential and industrial/commercial cover on both dates were displayed in medium olive and light olive respectively. Areas deemed to be open space were displayed in complex patterns of greens, browns, rusts, dark olives, dark greys and dark yellow. Areas deemed to be in woods on both dates were displayed in black. Because of the colour confusion of lands in the open space class, it was difficult to identify conversion when open space was the cover type at the time of the first image capture. For this reason land in the development phase of the land conversion process during the first date, second date, or both dates of image capture, was singled out as the best, reliable indicator of land conversion.

In the first treatment of the second phase , sample pixel change status was compared with change statue for identical locations on aerial photographs and ancillary land cover information. In the second treatment the multidate image was subjected to a supervised maximum likelihood classification based on five categories of no change (residential, industrial/commercial, open space, woods and development) in 1986 and 1987, and two categories of change (development in 1986 only and development in 1987 only). (See Figure 23.) One additional category present in Tables 3 and 4 (development between 1986 and 1987) accounted for conversion occurring between the two dates of image capture and, therefore, was missed in the analysis. Data in this category was obtained from ground truth sources and is included in Tables 3 and 4 so that all 930 pixels in the sample are reconciled.

An important distinction can be drawn between the first and second treatments of both phases of the methodology. In the first treatment of the separate composite image phase and the first

treatment of the multidate image phase change is determined more subjectively and directly by visually distinguishing colour hues. In the second treatment of both phases change is determined more objectively. A maximum likelihood classifier evaluates each preclassification pixel by comparing it to the spectral response pattern of predetermined land cover classes.

Accuracy Assessment

Systematic spatial sampling for accuracy assessment was determined in a consistent manner for the four change detection approaches. First, one pixel in the study area was identified by randomly generating a pair of lines, intersecting at right angles, within the study area. This randomly generated pixel served as the "anchor" and alignment reference for a 15 pixel square grid superimposed on the study area. A total of 106 grid intersection pixels thus were identified within the study area. A 3 x 3 sample pixel block was centred and superimposed over each grid intersection pixel. These 3 x 3 pixel blocks constituted the sample for the accuracy assessment. Eight pixel blocks along the southern boundary of the study area were truncated leaving a total of 930 pixels in the sample. This sampling method was selected because it was simple to apply and, assuming that a mix of land use/cover types was represented in any "cluster" of 106 pixel blocks, it satisfied the randomness criterion (Bryant and Russwurm, 1983).

Photomaps at a scale fo 1:5,000 for April, 1986 and April, 1987 provided the principal means for confirming the accuracy of information contained in the satellite images. Additional information on land cover employed to augment the photomaps included topographic maps produced by the Ontario Basic Mapping Program at scales of 1:20,000, 1:10,000 and 1:2,000; land use reports from the City of Scarborough planning department; airborne MSS images with 2.5 x 2.5 m pixels (Johnson and Howarth, 1987); hand-held oblique aerial photographs using colour transparency film in a 35 mm camera; and field reconnaissance. From this information a master land cover/ land cover change ground check sheet was prepared for the 930 pixel sample sites.

Visually interpreted or computer assigned land cover and land cover change status for each of the 930 pixel sample sites was noted on 2 coding sheets for each of the 2 separate composite images and 1 coding sheet for each of the 2 multidate images. A paired comparison between pixel status on coding sheets and pixel status on the master ground check sheet was carried out to assess accuracy.

Analysis

In Table 1, an accuracy assessment of the two visually compared false colour separate images is presented. An overall accuracy level of 78.9 % masks considerable variation among individual land cover classes. Overall accuracy among land cover classes undergoing conversion is only 62.1 %. Among classes not undergoing conversion open space exhibits the largest percentage of errors of omission with considerable confusion for residential and woods in the no conversion group and with the conversion categories involving industrial/commercial and residential. Woods also exhibits the largest percentage of errors of commission with 17 of 18 pixel errors due to woods being misinterpreted as open space.

Interpreted Land Use

Conversion	No Conversion					Rural to Urban Conversion								Other							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20*	21**
1 Residential	194	11	25	1	.	.	3	.	.	.	.	.	.	.	.	.	.	.	234	40	17
2 Industrial. Commercial	12	144	7	.	3	1	3	2	.	.	.	.	.	.	.	.	.	.	172	28	16
3 Open Space	36	3	247	17	.	.	1	4	7	6	.	.	.	.	.	3	.	.	324	77	24
4 Woods	.	.	2	49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51	2	4
5 Development	.	1	.	.	29	4	.	1	.	.	.	.	.	.	.	.	.	.	35	6	17
6 Development to Indust./Com	.	9	.	.		3	13	.	.	1	.	.	.	.	.	.	.	.	.	26	13
7 Development. to Residential	4	1	.	.	.	.	26	.	.	.	.	.	.	.	.	2	.	.	33	7	21
8 Open Space to Development	.	.	.	.	.	6	.	15	.	.	.	.	.	.	.	1	.	.	22	7	32
9 Open Space to Indust./Com.	.	7	.	.	1	.	.	2	2	.	.	.	.	.	.	.	.	.	12	10	83
10 Open Space to Residential	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	1
11 Woods to Development	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12 Woods to Indust./Com	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13 Woods to Residential	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14 Urban to Development	.	5	.	.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5
15 Urban to Rural	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16 Development to Rural	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.	.	14	.	.
17 Rural to Rural	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1		
18 Urban to Urban	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19 Total Pixels	246	181	281	67	36	24	34	24	10	6	.	.	.	.	.	20	1	.	930	.	.
20 Errors of Commission	52	37	34	18	7	11	8	9	8	6	.	.	.	.	.	6	.	.	.	196	.
21 Percentage Error**	21	20	12	27	19	46	24	38	80	100	.	.	.	.	.	30	.	.	.	.	.

*Errors of Omission **Rounded to nearest unit.

Overall Accuracy: 734/930 x 100 = 78.9%. Confidence Interval = +/-2.6 at 95% probability level.

Change Accuracy: 71/114 x 100 = 62.1%. Confidence Interval = +/-8.9 at 95% probability level.

Table 1. Detection of land cover change in the Scarborough Study Area by visually comparing two SPOT-1 false colour composite images. SPOT images were captured in the multispectral mode, 20 m ground resolution, for July 22, 1986 and June 4, 1987.

Among classes undergoing conversion and with 10 or more pixels involved, the conversion of open space and development to industrial/commercial exhibits the largest percentage of error of omission. Errors of commission for all categories do not differ markedly from errors of omission.

In the "other conversion" group 15 of 21 pixels were identified correctly as undergoing "reverse" conversion. Fourteen pixels were correctly judged to have converted from development to open space: instances where herbaceous vegetation ground cover had regenerated after completion of the construction phase of land development. In one instance farmland had reverted to woods. Five Pixels were incorrectly interpreted as remaining in the industrial/commercial category at both dates when, in fact, they shifted from industrial to open space: instances where materials stored outdoors on industrial sites were replaced by a thin cover of herbaceous vegetation.

An accuracy assessment of the separate images, modified by supervised classification, is presented in Table 2. A considerable decline in overall accuracy by 21.4 % and change accuracy by 24.4 % is evident; the largest proportion of the error occurring in the land conversion group rather than in the no conversion group as was the case in Table 1. Unusually large errors of commission occurred as a result of the prediction that 112 open space pixels converted to residential when, in fact, they remained either in open space or residential categories. Large numbers of industrial/commercial and open space "no conversion" pixels were misclassified as "other conversion" pixels. Errors of commission in the "other conversion" category increased from 27 pixels in Table 1 to 124 pixels in Table 2, only 37 pixels fewer than errors of commission in the "rural to urban conversion" category. Furthermore, this group of "other conversion" errors is counter intuitive to the normal direction of land conversion on the rural-urban fringe and, therefore, of particular concern.

Conversion	No Conversion				Interpreted Land Use: Rural to Urban Conversion								Other							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20*
1 Residential	166	3	8	.	.	.	.	.	45	.	.	1	.	2	.	2	7	234	68	29
2 Industrial/ Commercial	26	86	2	.	3	9	1	.	6	8	.	.	.	5	13	1	.	12	172	86	50
3 Open Space	36	.	164	2	.	.	.	1	1	67	.	.	.	.	35	.	16	2	324	160	49
4 Woods	.	.	2	45	.	.	.	.	.	.	.	.	.	.	.	.	4	.	51	6	12
5 Development	.	.	.	.	31	1	.	.	1	.	.	.	.	.	.	2	.	.	35	4	11
6 Development to Indust./Com.	.	4	.	.	.	8	5	.	.	2	.	.	.	2	1	1	.	4	26	18
7 Development to Residential	9	2	.	.	.	10	.	.	4	.	.	.	.	4	1	.	3	33	23	70
8 Open Space to Development	1	.	2	.	7	4	.	7	.	.	.	.	.	1	.	.	.	1	22	15	68
9 Open Space to Indust./Com.	1	1	.	.	.	.	.	.	4	1	.	.	.	.	2	.	.	3	12	8	67
10 Open Space to Residential	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	1	100
11 Woods to Development	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12 Woods to Indust./Com	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13 Woods to Residential	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14 Urban to Development	.	.	.	.	2	3	.	.	.	.	.	.	.	.	.	.	.	.	5	5
15 Urban to Rural	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16 Development to Rural	.	.	.	.	.	1	.	.	.	.	.	.	.	.	13	.	.	14	1	7
17 Rural to Rural	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.
18 Urban to Urban	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19 Total Pixels	239	96	178	47	42	25	17	8	12	128	.	.	1	8	58	18	23	31	930	.	.
20 Errors of Commission	73	10	14	2	11	17	7	1	8	127	.	.	1	8	58	5	22	31	.	395	.
21 Percentage Error**	31	10	8	4	26	68	41	13	67	99	.	.	100	100	100	28	96	100	.	.	.

*Errors of omission **Rounded to nearest unit.

Overall Accuracy: 535/930 x 100 = 57.5%. Confidence Interval = +/- 3.2 at 95% probability level.

Change Accuracy: 43/114 x 100 = 37.7%. Confidence Interval = +/- 8.9 at 95% probability level.

Table 2. Detection of land cover change in the Scarborough Study Area by comparing two SPOT-1 colour composite images modified by supervised classification. SPOT images were captured in the multispectral mode, 20 m ground resolution, July 22, 1986 and June 4, 1987.

Table 3 presents an accuracy assessment of a visually interpreted multidate image. Overall accuracy is 59.9% and change accuracy is 31.6%. Percentage errors of omission of 50 % or larger are noted for the residential category and the 3 land cover change categories.

An accuracy assessment of the multidate image, modified by supervised classification, is presented in Table 4. Overall accuracy has increased by 20.0% and change accuracy has increased by 28.0 % over results obtained from the visual interpretation of the multidate image. Errors of omission are reduced for all but the "development in 1986 and 1987" land cover category while errors of commission are reduced for all but the "development in 1986" category.

	Interpreted Land Use										
	No Conversion					Conversion					
	1	2	3	4	5	6	7	8	9	10*	11**
1 Residential	117	50	62	5	.	.	.	.	234	117	50
2 Industrial/ Commercial	41	99	17	.	15	.	.	.	172	73	42
3 Open Space	59	11	237	5	.	.	12	.	324	87	27
4 Woods	.	.	13	38	.	.	.	.	51	13	25
5 Development in 1986 and 1987	.	1	1	.	29	2	2	.	35	6	17
6 Development in 1986	9	10	25	.	2	27	.	.	73	46	63
7 Development in 1987	1	.	2	.	12	4	10	.	29	19	66
8 Development between 1986 and 1987	.	.	11	1	.	.	.	.	12	12	100
9 Total Pixels	227	171	368	49	58	33	24	.	930	.	.
10 Errors of Commission	110	72	131	11	29	6	14	.		273	.
11 Percentage Error**	48	42	36	22	50	18	58	.	.	.	.

*Errors of Omission **Rounded to nearest unit

Overall Accuracy: 557/930 x 100 = 59.9%. Confidence Interval = +/- 3.2 at 95% probability level.
Change Accuracy: 36/114 x 100 = 31.6%. Confidence Interval =+/- 8.6 at 95% probability level.

Table 3. Detection of land cover change in the Scarborough Study Area by visually assessing a SPOT-1 multidate composite image. The composite image was created from band 2 of two multispectral mode, 20 m ground resolution images captured July 22, 1986 and June 4, 1987.

	Interpreted Land Use										
	No Conversion					Conversion					
	1	2	3	4	5	6	7	8	9	10*	11**
1 Residential	178	15	38	.	.	3	.	.	234	56	24
2 Industrial/ Commercial	27	135	1	.	6	3	.	.	172	37	22
3 Open Space	37	3	278	.	.	5	1	.	324	46	14
4 Woods	1	.	.	50	.	.	.	.	51	1	2
5 Development in 1986 and 1987	.	.	.	.	34	.	1	.	35	1	3
6 Development in 1986	3	7	8	.	1	50	4	.	73	23	32
7 Development in 1987	.	2	.	.	4	5	18	.	29	11	38
8 Development between 1986 and 1987	.	4	7	1	.	.	.	.	12	12	100
9 Total Pixels	246	166	332	51	11	66	24	.	930	.	.
10 Errors of Commission	68	31	54	1	11	16	6	.		187	.
11 Percentage Error**	28	19	16	2	24	24	25	.	.	.	.

*Errors of Omission **Rounded to nearest unit

Overall Accuracy: 743/930 x 100 = 79.9%. Confidence Interval = +/- 2.6 at 95% probability level.

Change Accuracy: 67/114 x 100 = 59.6%. Confidence Interval = +/- 9.0 at 95% probability level.

Table 4. Detection of change in the Scarborough Study Area by assessing a SPOT-1 multidate composite image, modified by supervised classification. The original composite image was created from band 2 of two multispectral mode, 20 m ground resolution images captured July 22, 1986 and June 4, 1987.

The two, highest overall accuracies and change detection accuracies are obtained in Table 1 for the visually interpreted separate images and in Table 4 for the multidate image, modified by supervised classification. Accuracies in the "no conversion" group are marginally superior for the separate images method. This is due, in part, to the inability of the multidate image method to identify development that has taken place between the two image dates.

Are there any differences in the performance of these two methods that might cause an analyst to select one method over the other? To answer this question the accuracy of each method was examined on the basis of pixel-by-pixel location. The separate images method correctly identified 734 of the 930 sample pixels while the multidate method correctly identified 743 of the 930 sample pixels. Five hundred and two of the 743 sample pixels were correctly identified, jointly, by the two methods. Of the remaining 240 pixels, 116 were correctly identified, only by the first method and 124 were correctly identified only by the other method. For the entire sample, the separate images method was able to correctly identify 1.7 times as many residential, no change pixels as the multidate method. The multidate method was able to correctly identify twice as many open space, no change pixels as the separate images method. Again, considering the entire sample, the separate images method was able to identify correctly five times as many development-to-residential change pixels as the multidate method. The multidate method was able to identify, correctly, two and one-third times as many development-to-industrial change pixels as the separate image method.

The study area was subdivided spatially into three sectors according to the general land use activities common to the rural-urban fringe of Toronto: These sectors included a thin band of rural land along the northern boundary, development land extending in an arc from northwest to southeast and, urban occupying the southwest third of the study area.
When the 240 sample pixels, identified correctly by one of the two methods, were examined within this spatial framework the relative strengths of the two methods did not change. In the urban sector the separate images method identified two and one-half times as many residential no change pixels as the multidate method. Also, in this urban sector this method identified correctly two and one-quarter times as many industrial/commercial no change pixels as the multidate method. In the rural sector the multidate method identified four and one quarter times as many open space no change pixels as did the separate image method. Two a lesser degree, the

multidate method outperformed the separate images method in identifying open space no change pixels in both the development and urban sectors as well.

Eighty six percent of the change pixels correctly identified by one or the other methods were located in the development sector. The relative success of the two methods in identifying change pixels in the development sector merely duplicates the results obtained for the entire sample.

There were 27 instances in which both methods incorrectly interpreted no change pixels and 40 instances in which both methods incorrectly interpreted change pixels. The proportion of these incorrect no change pixels to total pixels, by pixel class, ranged from 3 to 6 %. It is inferred that both methods performed equally for this group. For change pixels incorrectly interpreted by both methods the proportion of incorrectly interpreted change pixels to total change pixels ranged from 12 to 75 % with the development-to-residential change class having the smallest proportional representation and the agriculture-to-industrial/commercial change class having the largest proportional representation. In this worst case both methods incorrectly interpreted 3 out of every 4 open space-to-industrial/commercial sample pixels (but for a small n=12).

Discussion

Similar land cover change classifications have been produced for this study area employing Landsat MSS by Martin (1989). A visual comparison of Landsat MSS and SPOT XS imagery indicates that, with SPOT XS imagery, it was possible to detect much smaller individual parcels of land at greater spatial precision than could be achieved with Landsat MSS imagery. (See Figure 2.) The increase in spatial detail and precision, however, did not result in improved accuracy assessments. The highest levels of change detection accuracy obtained with SPOT imagery are lower than levels of change detection accuracy obtained with Landsat MSS. The reason for this is that other factors, such as classification system and multispectral classification algorithms, employed by an image processing computer, may not take advantage of imagery improvements.

When employing the separate images method the improved spatial resolution and precision produced higher accuracies for a quite detailed, 18 category land cover classification system. The multispectral classification produced lower accuracies because of much confusion between categories attributed to their structure and composition. Different land cover classes are frequently composed of

similar land cover types. Paved surfaces are commonly constructed of concrete or asphalt regardless of their location in residential, industrial/commercial or rural areas. Trees and grass are ubiquitous to the urban and rural segments of the rural-urban fringe. Furthermore, at a 20 m x 20 m spatial resolution the instantaneous field of view of the sensor may be smaller in size than the constituent land cover parcel (Martin *et al.*, 1988).

When employing the multidate image method, the improved spatial resolution and precision contributed to considerable visual confusion and resulted in much error. Multidate images do not provide as much contextual information as static images. Only when supervised classification was applied to this change image did the consistent application of decision rules in the multispectral classifier reduce this misclassification.

Because the multidate image method predicts change on the basis of the occurrence of land development it will overlook land conversion if the land development stage appears between the dates of image capture. (However, the separate images method, capable of identifying this type of change, produced poor results in this study in attempting to identify open space-to-industrial/commercial change.) As the monitoring interval increases the method will be subject to larger error. Furthermore, the method cannot provide information concerning pixel land cover before and after development.

Conclusion

The continuing, overriding goal of this research is to develop an accurate, cost effective method of monitoring rural-to-urban land conversion for Canadian metropolitan areas employing earth satellite imagery. As part of this goal we are attempting to identify and delimit the several stages of land development including 1) site clearance, 2) installation of services, 3) house construction, and 4) landscaping. In the first research project for CMHC, the principal investigator (Martin, 1985, 1986) explored the potential of U.S. Landsat MSS imagery for monitoring urban development in a test area of Metropolitan Toronto. In this current study the principal investigator has explored the capabilities of the new, French SPOT XS high spatial resolution imagery for achieving the land development monitoring goal.

This most recent research project has been guided by three research objectives. First, it has attempted to compare and evaluate the improved capabilities of SPOT XS with Landsat for monitoring

urban development. Second, it has compared computer-based interpretation with conventional visual interpretation of satellite imagery. Finally, it has attempted to accomplish the first two objectives within an analytical framework that permits comparison with the result of the first study.

Our attempt to compare Landsat and SPOT, directly, at the same location for approximately the same time period, was frustrated by the limited availability of cloud-free Landsat imagery. Any attempt to combine imagery from different satellites for identical or approximate image capture dates will be confronted frequently with this problem.

Computer enhanced imagery with improved spatial resolution, does not lead, invariably, to improved land cover change detection accuracies. Change detection by visually comparing two, false-colour, composite images produced higher accuracies than by comparing these same images modified by supervised classification. On the other hand, change detection by visually examining a multidate, composite image produced lower accuracies than by examining this same multidate composite image modified by supervised classification. The highest levels of accuracies obtained in this study were not appreciably higher than change detection accuracies obtained in earlier studies employing Landsat MSS (Martin,1985, 1989).

Despite its demonstrated weaknesses in detecting change, SPOT XS satellite imagery offers a range of opportunities for advancing toward our research goals. As a result of the experience gained during this study several methods of improving change detection accuracies are proposed. Hard copy images (particularly acetate positive transparencies) might be examined for their land conversion information and compared against methods used in this study. The Procom III, a high quality optical transfer device, has proven to be a very useful tool for visual analysis (Gregory and Moore, 1986). Recent research indicates that SPOT XS imagery is enhanced visually by combining it with SPOT Panchromatic imagery (Howarth *et al.* , 1988). (However, the SPOT satellite does not record, simultaneously, in both these modes except by special request.)

Contextual information contained in a satellite scene and collateral information available from maps, and other spatially registered data including land registry and property assessment documents should be brought into change detection analysis. For the time being the inclusion of collateral information likely will be

carried out manually due to the difficulties of accurately and efficiently linking vector- based GIS data and raster- based remotely sensed data.

Change detection methods can be applied selectively within a study area in a way that utilizes their strengths. For example, in this study accuracy assessment provides evidence that the multidate method will produce more accurate results in rural areas while separate image comparison methods will produce more accurate results in urban areas.

New classification systems better suited to the spectral and spatial characteristics of SPOT XS should be devised and tested. Land cover classes should relate more closely to the basic land cover, elemental, building blocks of structure and composition. Improved computer classification algorithms will be needed to deal with these elemental building blocks. Together, these improved classification systems and classification algorithms applied, whenever possible, to integrated SPOT XS/Panchromatic imagery should lead to higher change detection accuracies.

At this stage in the evolution of satellite-based remote sensing technology it is not possible to monitor land development at a level of accuracy that satisfies the needs of participants in the development process; including land developers and builders, planners, engineers and real estate interests. Large scale aerial photographs, rich in visual information, are much more useful for studying specific development sites and for monitoring changes at those sites.

However, if monitoring of land development, with a specific concern for the occurrence or non-occurrence of rural-to-urban land conversion over an entire metropolitan region, is of primary concern, then satellite imagery offers advantages not available from aerial photographs. A primary advantage of satellite imagery over aerial photographs for large area studies is cost reduction. Another study suggested a two-thirds cost saving in the employment of satellite imagery (Martin, 1986). The instantaneous, synoptic view of satellites, so important for change detection in large areas, cannot be equalled by aerial photographs. In large area studies human error, associated with the manipulation of large numbers of photographs, by interpretation and mapping teams, becomes an important concern. Indeed, this error may exceed the interpretation error discussed in this report.

Despite their quite different origins and physical properties both aerial photography and satellite imagery are dependent on clear skies for image capture. As the number of resource satellites orbiting the earth increase, the interval between overflights will be reduced and the probability of good quality imagery will increase. With the launching of the European Space Agency's ERS-1 satellite containing a high spatial resolution synthetic aperture radar earth imaging through cloud cover will provide a flexibility to information collection not presently available to conventional satellites.

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